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Dimensions of Disaster During Hurricane Katrina: Landscape, Levees, and the Least Fortunate

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Abstract:

In 2005 Hurricane Katrina made landfall in Southeastern Louisiana as a powerful Category Three hurricane. The hurricane protection systems in place for the city of New Orleans and surrounding parishes were overwhelmed sending billions of gallons of water into local communities. This atypical flood volume inundated 80% of New Orleans, impeding rescue efforts and devastating infrastructure and emergency resources. Over 1,500 lives were lost and an estimated 125 billion US dollars were spent on emergency response, recovery, and reconstruction. Hurricane Katrina is the worst disaster in the United States in over a century.

This paper analyzes why Hurricane Katrina was such a catastrophe. Three major reasons for disaster are identified: construction of piecemeal levee systems, wetland loss, and social vulnerabilities. Throughout the history of southeastern Louisiana's settlement, the natural hydrography was manipulated in order to protect life and property from flooding; a fragmented levee system was constructed based on underestimated storm risk resulting in the hurricane protection system that failed during Hurricane Katrina. Similarly, increased residential development, canal building, and natural land subsidence processes have degraded natural wetlands which function as protective barriers from storm surges. The population of New Orleans exhibited high social vulnerabilities, as many Katrina victims lacked the tools, knowledge, and capabilities necessary to evacuate in a timely manner or to exercise other self-protective measures.

These three elements—fragmented levee systems, wetland degradation, and high social vulnerabilities—exacerbate the level of vulnerability of property and people along the Gulf Coast. In order to reduce the vulnerability, and the probability of a similar catastrophic event occurring, an analysis of Hurricane Katrina can be utilized to improve future mitigation planning. Better mitigation could yield improvements in levee quality; areas of dramatic wetland decline can be monitored and perhaps protected from future development, and heavily populated areas with high social vulnerabilities can be recognized and considered priority zones for mitigation plans.

Accronyms Commonly Used:

B-LLP	Barrier-Low-Level Hurricane Protection Plan
CWPPRA	Coastal Wetlands Planning, Protection, and Restoration Act Managing Agency
EIS	Environmental Impact Statements
FEMA	Federal Emergency Management Agency
HLP	High-Level Plan
IHNC	Inner Harbor Navigation Canal
LPHPP	Lake Pontchartrain Hurricane Protection Plan
MRC	Mississippi River Commission
MRGO	Mississippi River Gulf Outlet
NASA	National Aeronautics and Space Administration
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
SPH	Standard Project Hurricane
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

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Introduction – The Storm

Figure 1: Hurricane Katrina making landfall, August 29, 2005. NOAA Katrina Homepage.

On August 29, 2005 Hurricane Katrina battered the low-lying lands of the central Gulf states (Johnson 2006). The eyewall of the category three storm crossed over southern Plaquemines Parish, Louisiana with maximum wind speeds of 125 miles per hour (NOAA 2007). The devastation was widespread across the gulf coast as Katrina's damaging winds and storm surge stretched over 230 miles outward from the center (Graumann et al 2006). The city of New Orleans was pummelled by heavy rainfall, 100+ mile per hour winds, and in some areas a storm surge of up to 28 feet (NOAA 2007). Eighty percent of the metropolis of New Orleans was inudated by flood waters; some areas such as the Lower Ninth Ward and Lakeview were under up to twenty feet of water (Graumann et al 2006). Much of the infrastructure in New Orleans, such as transportation networks, schools, government buildings, and emergency response services were damaged leaving neighborhoods unrecognizeable, highways impassible, and electricity knocked out for over 1.7 million people (NOAA 2007). The storm overwhelmed protective seawalls and the intricate levee system in the region forcing hundreds of thousands of residents to evacuate or endure the dooms-day-like conditions. Hurricane Katrina claimed between 1500 and 1800 lives, making it the second most deadly hurricane event in US history, second only to the Galveston Island, Texas hurricane of 1900 (NOAA 2007).

In the weeks after the storm, Americans and the global community witnessed surreal imagery and tragic accounts of death and survival. The United States, one of the most developed and prosperous nations in the world, had endured a largescale natural disaster. Looting and violence broke out, surviviors were forced to wait on rooftops and in shelters for days without access to potable water and food, and corpses floated through toxic waters (Johnson 2006). In New Orleans and surrounding parishes the polluted mire remained stagnant for up to 43 days after Katrina's initial landfall (Johnson 2006).

Two flood maps (Figure 2 and 3) demonstrate the magnitude of flood waters in New Orleans Parish and the length of time it took for the waters to recede or be pumped out (NOAA 2006). Figure 2 shows the depth of flooding two days after the storm on August 31, 2005. Much of the city was flooded by four to eight feet of water, with some areas such as New Orleans East inundated by up to fifteen feet of water. Figure 3 shows flood waters still present on September 20, 2005. It took until October 11, 2005 for the floodwaters to be completely drained from the city's limits (Johnson 2006). Figure 4 and Figure 5 show before and after satellite imagery of the lower Mississippi River Delta. Flooding was extreme throughout Southeastern Louisiana in addition to the New Orleans metropolitan area.

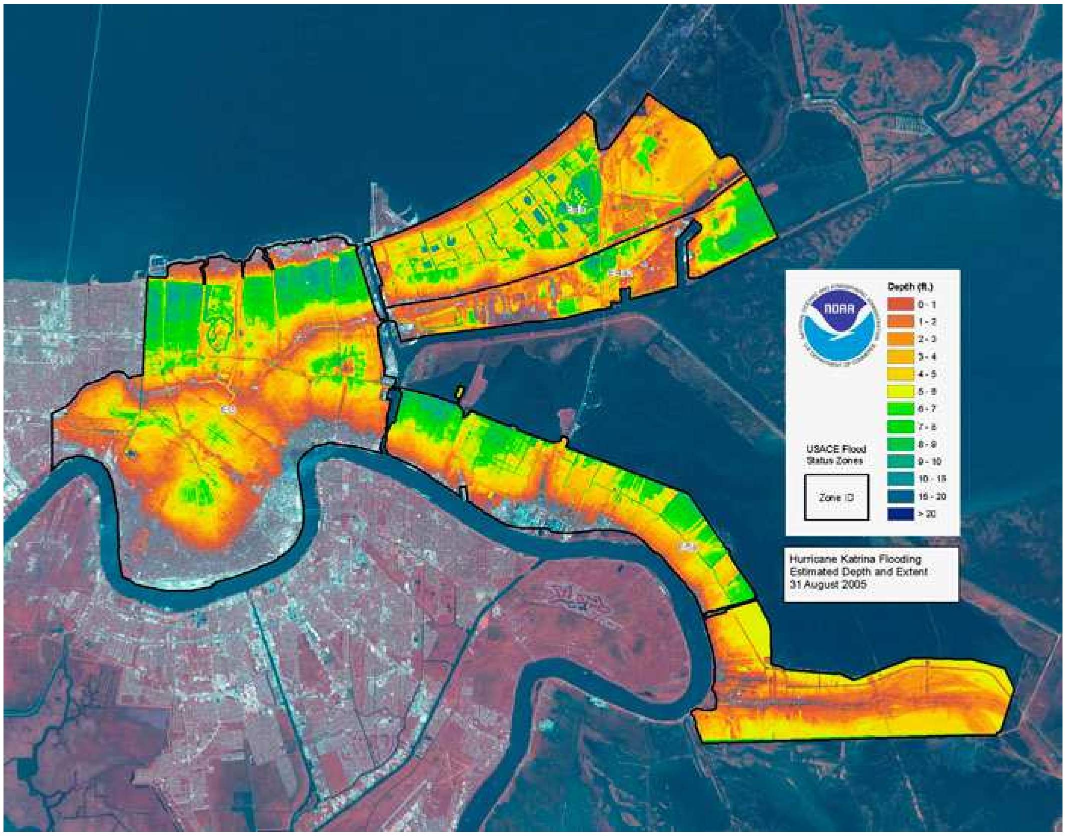

Figure 2: New Orleans Flood Map – August 31, 2005. Source: NOAA Flood Maps 2006.

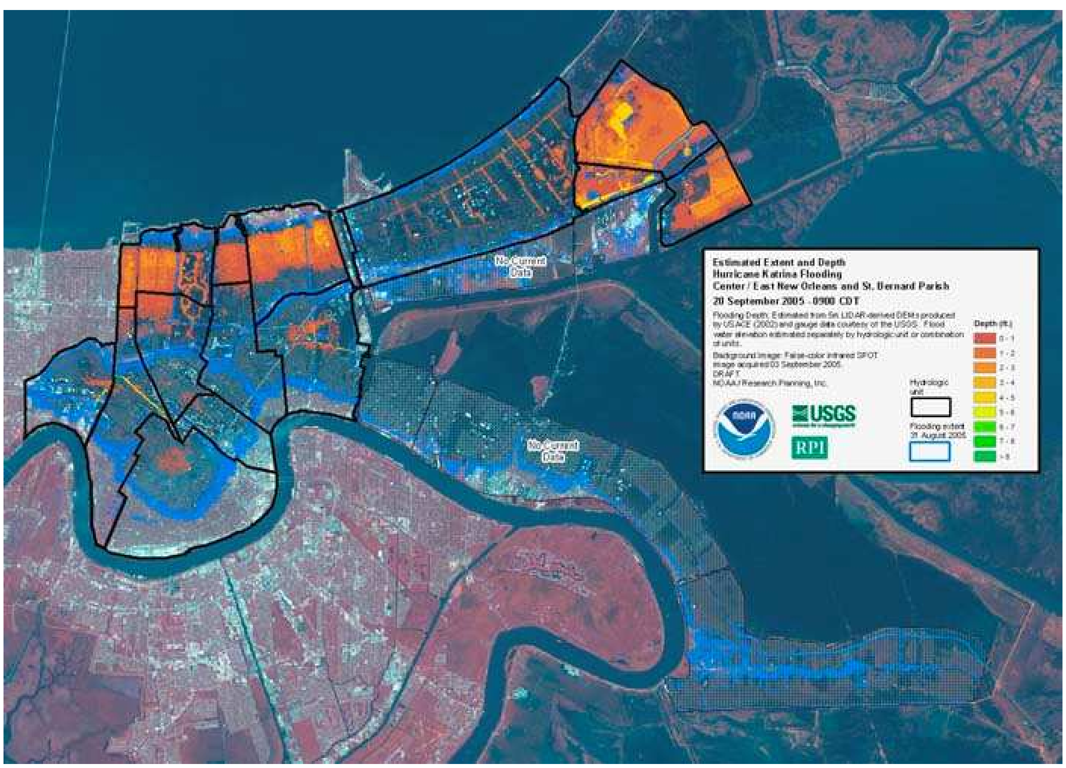

Figure 3: New Orleans Flood Map – September 20, 2005. Source: NOAA Flood Maps. 2006.

Figure 4: MS River Delta flooded from Hurricane Katrina on September 4, 2005. The coloring has been amplified to make the landscape changes more apparent. Source: NASA *Earth Observatory Terra-MODIS Satellite Imagery.* 2005.

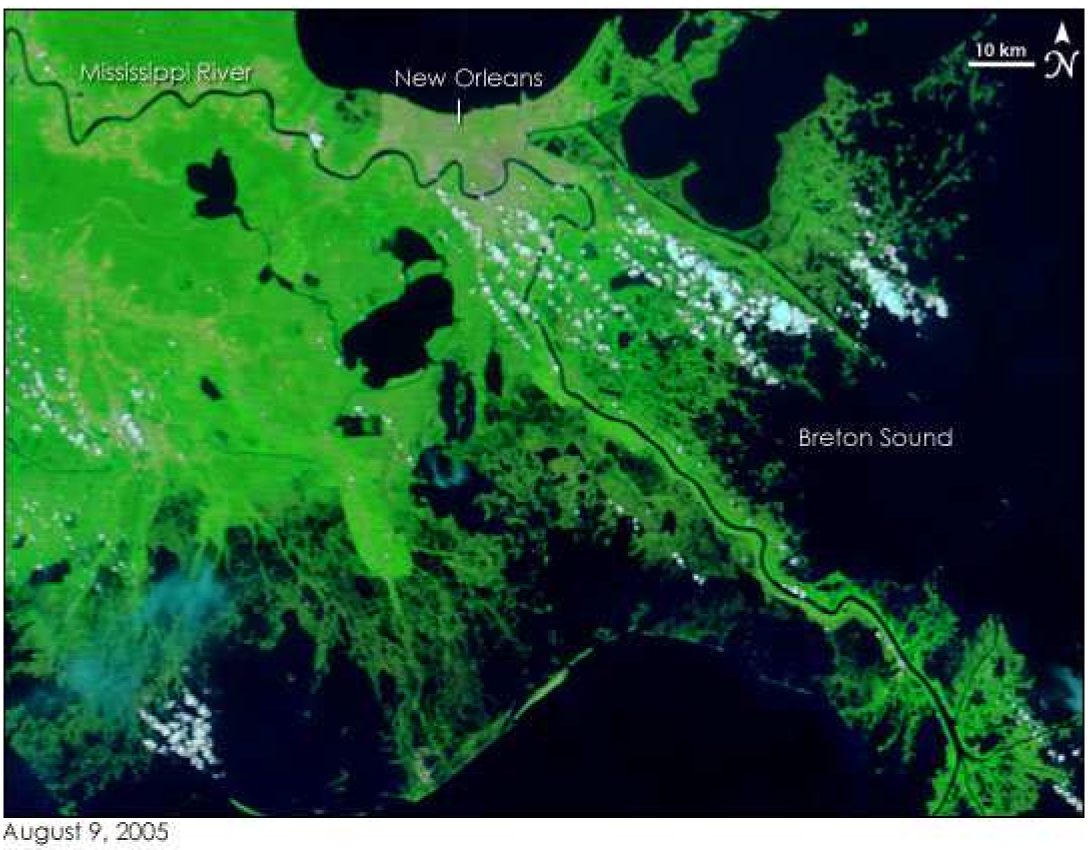

Figure 5: MS River Delta unflooded on August 9, 2005. The coloring has been amplified to make the landscape changes more apparent. Source: NASA *Earth Observatory Terra-MODIS Satellite Imagery.* 2005.

Hurricane Katrina had surprisingly large impacts; however, Hurricane Katrina was not the strongest storm in history to make landfall on the Gulf Coast. Hurricane Camille struck the same region of the central Gulf States in 1969 as a Category Five storm according to the Saffir-Simpson Hurricane Scale (Table 1). This scale is based upon a hurricane's maximum wind speed; categories three through five are considered major hurricanes, with categories four and five resulting in catastrophic damages and losses (Graumann et al 2006). At one point during its formation Hurricane Katrina was considered a Category Five; but, the winds died down considerably before making landfall in Louisiana on August 29 (Roth 2010). In the same 2005 hurricane season, Hurricanes Rita and Wilma also reached Category Five status and made landfall as intense Category Three hurricanes (Roth 2010). Neither Camille, Rita, nor Wilma produced the widespread and extensive amount of flooding and damage as witnessed during Hurricane Katrina.

Saffir-Simpson Hurricane Scale		
Category	Knots	(MPH)
1	64-82	(74-95)
2	83-95	(96-110)
3	96-113	(111-130)
4	114-135	(131-155)
5	136 and >	(156 and >)

Table 1: Categorization of hurricanes' strength based upon wind speed. Source: Graumann et al. 2006.

The aftermath of Hurricane Katrina reveals continued vulnerability to natural disasters even for a highly developed nation and a region that has experienced many hurricane disasters. The storm exposed the shortcomings of engineering as well as emergency response. In order to reduce the likelihood of future hurricane losses in the Gulf states and other exposed coastal geographies, an analysis of the impact of Hurricane Katrina, with attention to the weaknesses in adaptation that it revealed, can provide lessons and insights into the relationships between humans and the environment that make the region vulnerable. This paper proposes three main reasons for the extent of destruction during Hurricane Katrina: piecemeal levee and seawall construction, wetland and natural buffer zone decline exacerbated by development of unsuitable lands and natural subsidence processes, and high levels of social inequalities that resulted in an extremely vulnerable population of non-evacuees. Analysis of these three key components could yield insight to improve future mitigation, prevention, and planning systems.

Background – The Geography of New Orleans

The Mississippi River Delta is a low-lying geographic region characterized by wetlands, estuaries, and the meandering Mississippi River (CWPPRA 2011). The River Delta is located between Mississippi and Lousiana where the Mississippi River makes its way to the Gulf of Mexico (CWPPRA 2011). The river dominates the landscape of southeastern Louisiana and southwestern Mississippi, creating an alluvial valley with routine flooding (Miller and Rivera 2008). Geologic sediment samples indicate that the river has changed its route to the Gulf of Mexico through time depending on land elevation, sediment composition, and sea level (Van Heerden and Bryan 2006); this indicates a transient state for the entire delta-plain. Van Heerden and Bryan refer to the Louisiana coastal zone as a "living landscape," which exhibits a dynamic balance between sediment deposition and recession (2006, p 153). Before early settlement and land development, cypress swamps and marshes extended further south of Lake Pontchartrain than seen today (Kindinger 2001). Similarly, the barrier islands in the Gulf of Mexico were more prominent, acting as a natural line of defense against hurricane storm surges (Kindinger 2001). Today, the living landscape of Louisiana exists as an amalgamation of concrete, swamp, river, and infrastructure with high levels of wetland decline. (NASA 2005).

New Orleans is referred to as the “Crescent City” due to its crescent-moon-like curvature along the banks of the Mississippi River (Miller and Rivera 2008). To the north of New Orleans, a levee system outlines the coast of Lake Pontchartrain, a large brackish water estuary that provides habitat for a plethora of flora and fauna as well as recreational opportunities for surrounding populations (Moreau 2006). To the east, Orleans Parish is bordered by the Inner Harbor Navigation Canal (IHNC) otherwise known as the Industrial Canal (Moreau 2006); beyond the IHNC is New Orleans East, a newer residential section bordered by Lake Borgne, the gateway to the Gulf of Mexico (Moreau 2006). New Orleans and neighboring parishes are bordered to the south by the Mississippi River as it winds its way into the Gulf of Mexico (Moreau 2006); to the west of Orleans Parish lies the 17^{th} St Canal and Jefferson Parish (Moreau 2006).

The major water features of New Orleans along with notable neighborhoods and roadways are visible in Figure 6. Figure 6 shows that New Orleans is bordered by water on all sides; to the north there is Lake Pontchartrain, to the east the IHNC which connects to the southern border of the Mississippi River, and then the 17th St. Canal on the western border which reconnects with Lake Pontchartrain. In addition to being surrounded by water, the city basin is located mostly below sea level with some areas up to eight feet below the sea surface (Figure 7). The low elevation of the city is problematic as the entire region is susceptible to flooding and storm surges. Figure 7 (below) reveals the predicament of New Orleans’ bowl-like geography. In flooding situations, the surrounding water features spill into the areas lying below sea-level, inundating most of the city.

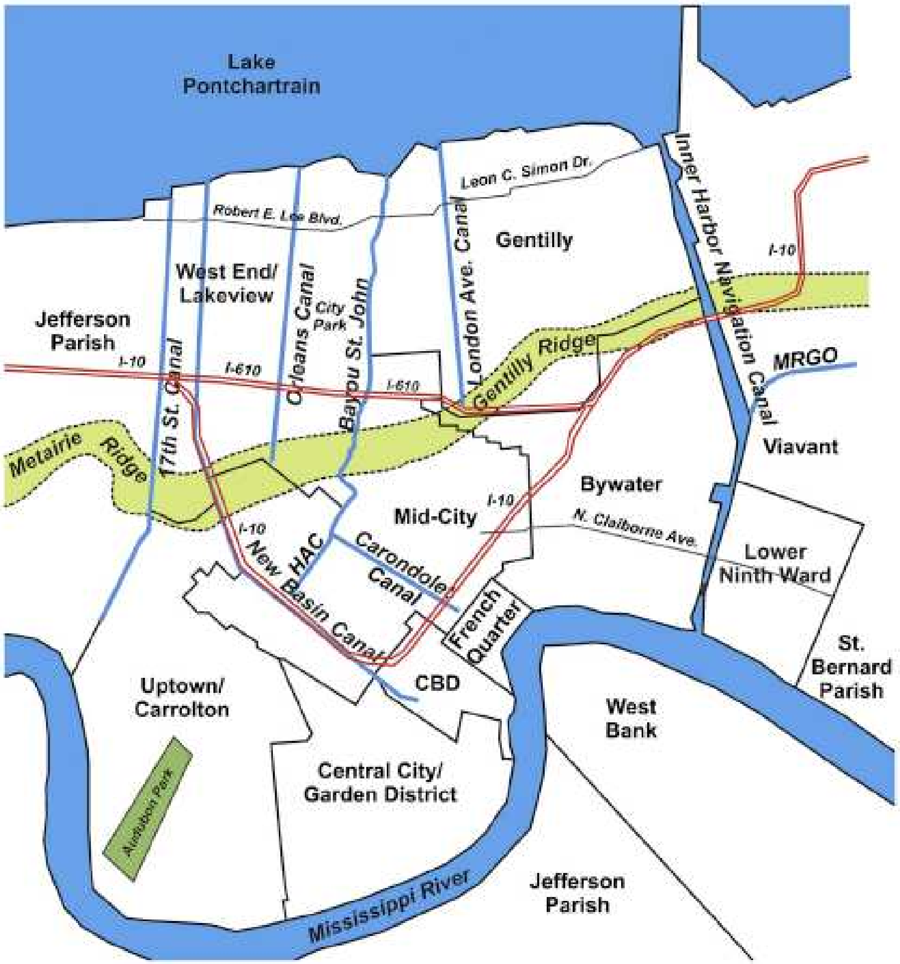

Figure 6: A generalized map of prominent New Orleans features and the surrounding water systems. Source: Rogers, J.D. 2008.

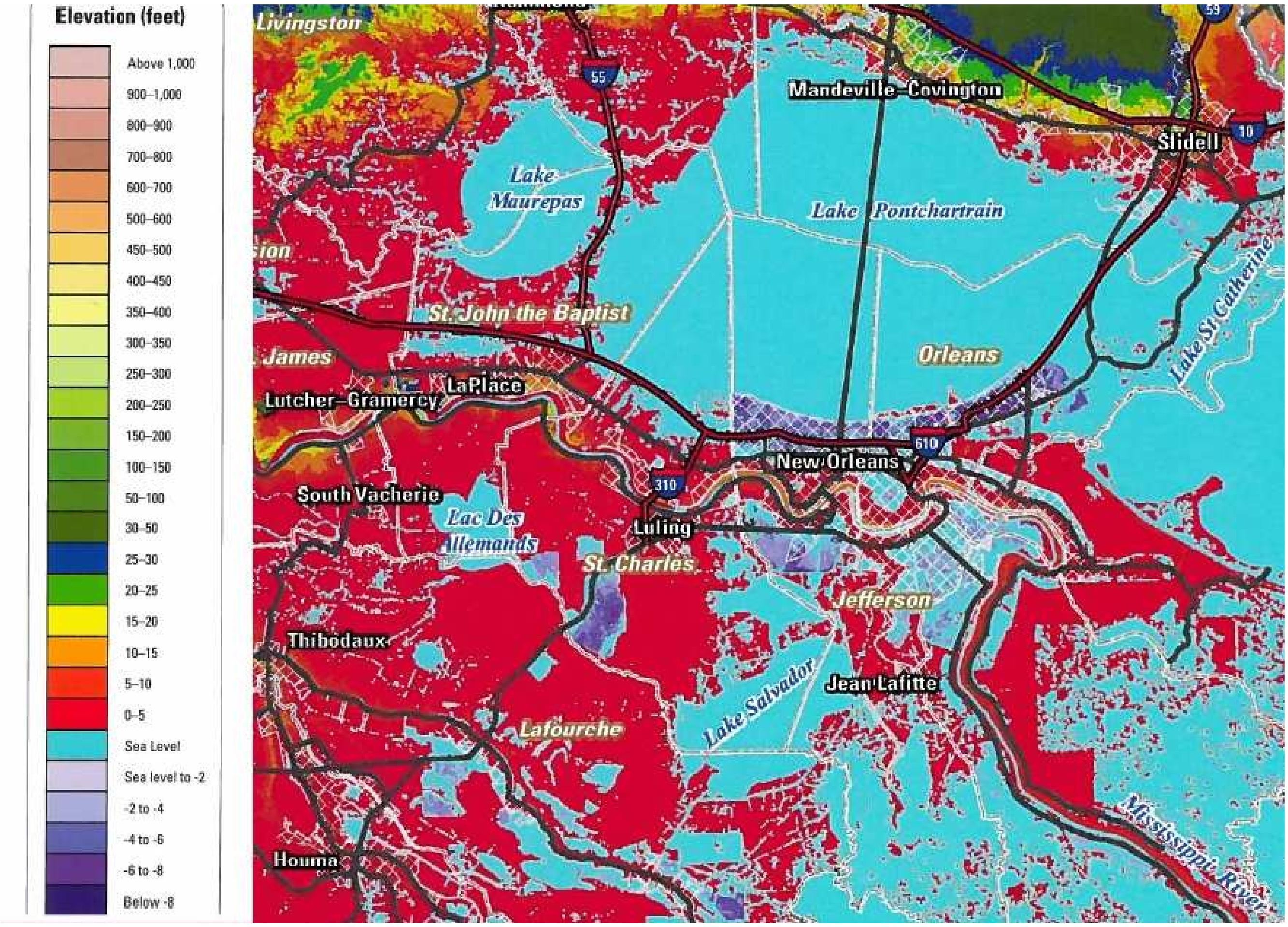

Figure 7: Elevation of New Orleans and surrounding parishes. Scale: 1: 700,000. Source: Kosovich, John J. 2008.

The Construction of the Pre-Katrina Landscape – The Crescent City: 1733 to 1927

The night before Hurricane Katrina struck the central Gulf region, the landscape existed as a product of hundreds of years of human alteration. The history of New Orleans is marked by frequent hurricanes, storm surges, and river flooding events; these events were perceived as manageable by early white settlers of the Mississippi River Delta (Miller and Rivera 2008). Beginning with the founding of New Orleans in 1733 by French colonists a precept was spread: the New Orleans region was a gateway that must be tamed in order to establish a pivatol port bringing prosperity to the land (Miller and Rivera 2008). The mouth of the Mississippi was seen as a tempestuous entity and simultaneously as a financial wellspring. Miller and Rivera describe this desire to conquer the “shortcomings of the New Orleans topography” as “surprising evidence of what men will endure” (2008, p 26). The annual drowning of the land and non-routine flooding from frequent storms would prove to be harder to manage than originally believed, and they continue to be a “shortcoming” of the Mississippi River Delta today.

Initially, the Crescent City was developed to have a network of roadways known as the "sixty-six block grid" (Miller and Rivera 2008). The sixty-six block grid was built on the highest ground between the Mississippi River and Lake Pontchartrain (Miller and Rivera 2008). This business epicenter did not provide enough housing for early settlers, however, which led to the establishment of "faubourgs," or suburbs (Miller and Rivera 2008). The faubourgs were built to the north and west of the sixty-six block grid in low-lying, swampy areas. The faubourgs were subject to overspill from the neighboring Lake Pontchartrain during storm events, in addition to seasonal flooding from the Mississippi River (Miller and Rivera 2008). In order to cope with the annual saturation of the land local farmers and land owners buffed up the landscape’s natural levees (Miller and Rivera 2008). There was neither congruency nor communication between levee systems and their constructors, resulting in a piecemeal and permeable “system,” and, this, continued flooding of the terrain (Miller and Rivera 2008).

Major levee failures occurred during the city’s first century as a port. Notably, on May 5, 1816 and May 4, 1849, the Mississippi River breached the levees flooding St. Charles Place and the French Quarter (the sixty-six block grid) with up to eight feet of water (Miller and Rivera 2008). In addition, major hurricanes afflicted the region. The "Great Louisiana Hurricane" on August 9, 1812 sent fifteen feet of water into St. Bernards Parish just across the river from New Orleans proper; the "Great Barbados Hurricane" of 1831 swelled the levels of Lake Pontchartrain, creating a three foot storm surge that flooded New Orleans' suburbs (Miller and Rivera 2008). During this era, the highest levee in New Orleans was a natural levee composed of silt deposits (Van Heerden and Bryan 2006). This levee stood ten feet above the city floor, which rested nearly eight feet below sea level, indicating only a two foot wall above sea level of protection from storm surges and annual flooding (Van Heerden and Bryan 2006).

The mid-to-late-nineteenth century again saw major flooding of the Mississippi River. Local governments were in charge of the levees and floodwalls up until the 1860s, when the U.S. federal government decided to provide financial assistance in order to establish a “continuous levee system” (Miller and Rivera 2008, p 29). This continuous system was proposed as a method to resolve *seasonal* flooding in the New Orleans area and to benefit navigation networks, not to provide flood protection from hurricanes (Miller and Rivera 2008). Thus, the levee construction was organized around containing the swelling of the Mississippi River, not providing protection along the Gulf of Mexico or from Lake Pontchartrain.

In need of an overarching organization to manage levee building, in 1879 the U.S. government established the Mississippi River Commission (MRC) headed by the United States Army Corps of Engineers (USACE); the MRC was designed to be in charge of levee and canal construction and development for the entire Mississippi River Delta (Miller and Rivera 2008). The MRC initially set out constructing levees to support navigation and channeling in the Mississippi River Delta, but after widespread severe flooding in 1927, the U.S. government mandated that levee building and canal construction provide flood and storm surge protection to prevent life and property losses within the delta region (Van Heerden and Bryan 2006).

The federal government shifted the focus of levee construction towards flood management due to the increasing population in New Orleans. From 1900 to 1950 the population doubled in size (USGS Coastal and Marine Geology Program 2010). Table 2 demonstrates that dramatic increase in New Orleans’ population from 1900 to 1950 (USGS Coastal and Marine Geology Program 2010). This escalation prompted new development in areas further away from the highest ground at the city center (Moreau 2006). These suburbs were built on below-sea-level, wetland terrain, creating communities that were vulnerable to flooding (Van Heerden and Bryan 2006). This new development also necessitated new levees.

From its early settlement, New Orleans was a region marked by fluxing and tempestuous water features. The shortcomings of the regional topography, however, were considered to be problematic but controllable. Despite repeated flooding events, development increased and the population expanded. In order to improve navigation canals and handle seasonal flooding for the growing city, the MRC was created to oversee levee construction for the lower-river delta. In 1927, nearly two centuries after New Orleans was founded, the purpose of levee construction was shifted towards hurricane protection. The early history of New Orleans suggests that the region was quickly over-populated and under-protected, leaving the dilemma of how to protect lives and property to future generations.

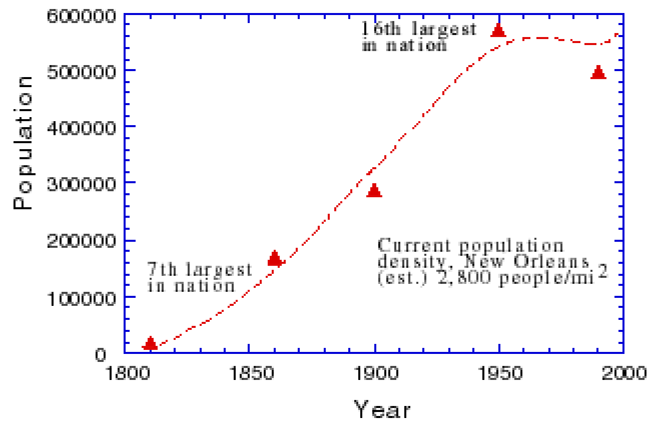

Table 2: Population of New Orleans Chart. Source: USGS Coastal and Marine Geology Program. 2010.

The Construction of the Pre-Katrina Landscape – Flood Management: 1927 to 1965

From 1927 to 1960 the USACE constructed the levee and canal system that remains the heart of the modern levee system in place in New Orleans (Van Heerden and Bryan, 2006). Floodwalls were built in front of earthen levees to bar off Lake Pontchartrain, the Jefferson Parish levee and the INHC were constructed, and the Mississippi River's seasonal inundation of New Orleans was mitigated by the construction of the Bonnet Carre Spillway, just 23 miles north of New Orleans (Moreau 2006;

NOAA 2011). The Bonnet Carre Spillway is a floodgate-controlled outlet that can redirect up to 250,000 cubic feet of water per second into Lake Pontchartrain (NOAA 2011). The Spillway is currently still in use; its construction prevented what geologists predict would have been an eventual merging of the Mississippi River and the Atchafalaya River (Van Heerden and Bryan 2006). By redirecting seasonal floodwaters, the Bonnet Carre Spillway has allowed the Mississippi River to maintain its current flow path instead of fluxing in the direction of its overflowing waters (NOAA 2011).

With seasonal flooding "under control," the U.S. federal government sought to expand protection for storms. In 1965, Congress instructed the USACE to devise a hurricane and severe tropical storm protection plan that could harbor New Orleans from even the most severe of storms (Moreau 2006). The USACE proposed the Lake Pontchartrain Hurricane Protection Plan (LPHPPP) that was designed to protect the area from the Standard Project Hurricane (SPH) (Moreau 2006). The Standard Project Hurricane was described by the USACE as "the one that may be expected from the most severe combination of meteorological conditions that are reasonably characteristic of the region" (Moreau 2006, p 27). The USACE estimated the maximum winds of the SPH to be 100 miles per hour with a return period of two-hundred years, or an annual probability of .5% (Moreau, 2006, p 27). A return period refers to what Smith and Petley define as "the time that, on average, elapses between two events that equal, or exceed, a given magnitude" (2009, p. 55). In other words, the SPH, a Category Three hurricane on the Saffir-Simpson Scale, was expected to occur on average every two-hundred years.

The LPHPP contained two potential protection designs: the Barrier-Low-Level Hurricane Protection Plan (B-LLP) and the High-Level Plan (HLP) (Moreau 2006). The B-LLP involved dredging wetlands for barrier enhancement of the current levee system (Moreau 2006). The HLP was more costly and called for floodgates to be constructed at major canal entrances, functioning as a blockade to storm surges (Moreau 2006). The floodgates could be closed before storms made landfall preventing storm surges from rushing up canals and flooding the local neighborhoods (Moreau 2006). The Mississippi River Commission, which was now comprised of local levee bureaus, federal emergency management groups, and the USACE, chose to implement the B-LLP; however, both the B-LLP and the HLP were modelled after an undercalculated SPH (Richardson et al 2008).

Recent calculations performed by researchers at the National Hurricane Center and the National Weather Service (NWS) indicate that rather than a two-hundred year return period of a Category Three hurricane making landfall in southeastern Louisiana, there is a twenty year return period (Blake et al 2011). Figure 8 represents return periods of a Category Three strength storm or higher making landfall for the eastern coastal U.S. counties. Louisiana has one of the shortest return intervals, along with the southern coast of Florida and the coast of North Carolina, indicating a substantial under estimation by the USACE.

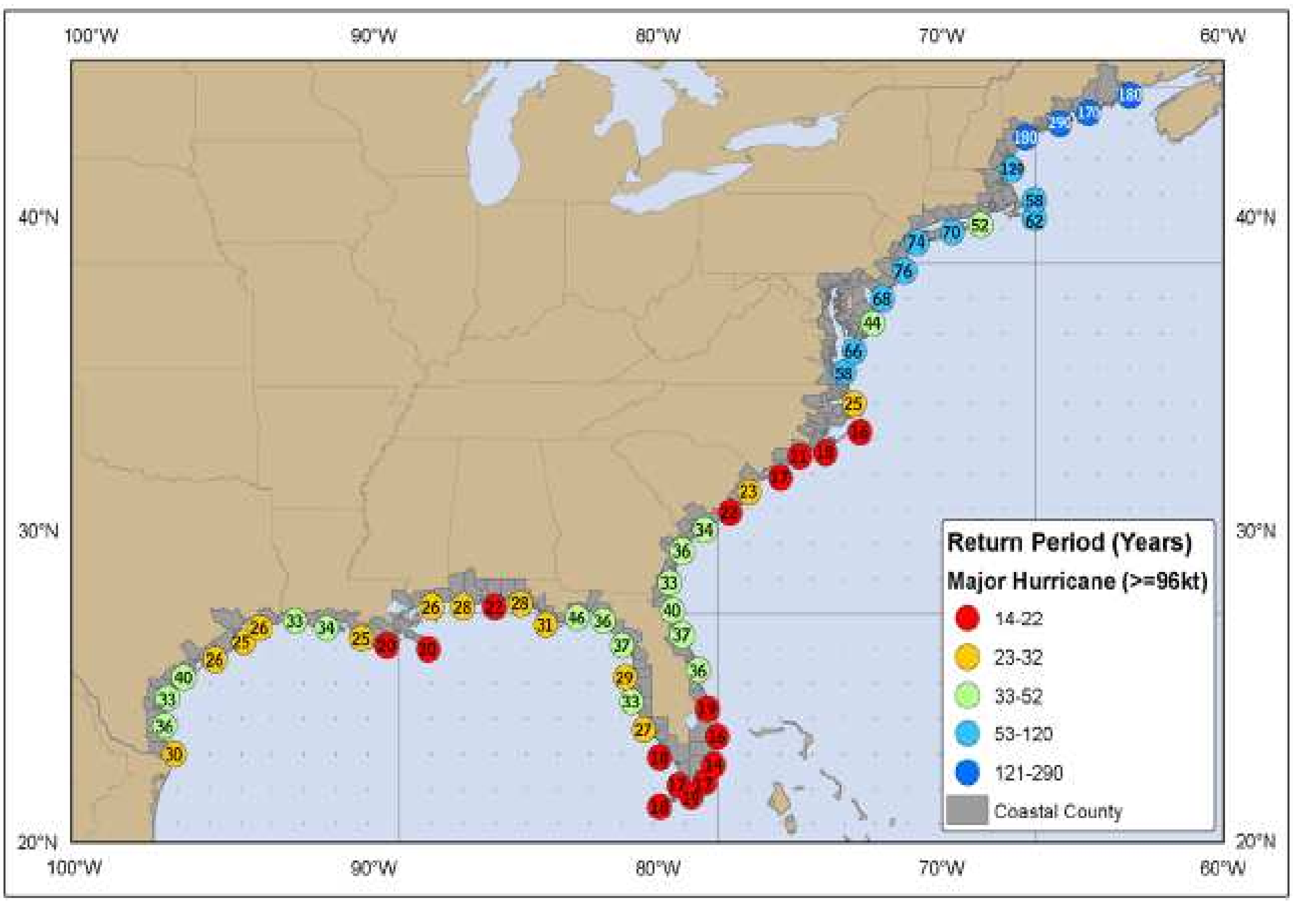

Figure 8: Estimated return periods for U.S. counties of a Category Three Hurricane or stronger making landfall. Blake et al. 2011.

Table 3, created by David Roth in conjunction with the NWS and NOAA, displays the number of hurricanes and tropical storms to strike the coast of Louisiana from 1850 through 2000 (2010, p 7). Striking refers to the eye-wall or a portion of the eye-wall passing over part of the state of Louisiana. Fifty-four hurricanes were reported to have made landfall in a one-hundred and fifty year time period; this indicates that a hurricane should be expected to make landfall in Louisiana on average every 2.8 years (Roth 2010). In the 1960s alone, four hurricanes that struck Louisiana, three of which matched or surpassed Category Three intensity (Roth 2010). This again would indicate a major underestimation of the SPH's return period.

Tropical Cyclone Strikes by The Decade

Decade	Hurricanes	Tropical Storms	Total
1850's	2	0	2
1860's	6	2	8
1870's	3	4	7
1880's	6	2	8
1890's	3	5	8
1900's	2	4	6
1910's	2	3	5
1920's	3	2	5
1930's	2	5	7
1940's	3	7	10
1950's	2	7	9
1960's	4	0	4
1970's	4	2	6
1980's	4	2	6
1990's	2	1	3
2000's	6	6	12
	===	===	===
	54	52	106

Table 3: Table displaying Hurricane or Tropical Storm strikes for the entire state of Louisiana. Source: Roth, David. 2010.

Besides a miscalculated return period, a case can be made that the USACE underestimated the intensity of the SPH; hurricanes of greater magnitude have directly and indirectly struck the Mississippi River Delta (Blake et al 2011). In 1969, just four years after the LPHPP was proposed, Hurricane Camille made landfall on the border of southeastern Louisiana and southwestern Mississippi as “the most intense hurricane known to ever make landfall in the United States” based upon wind speed and storm pressure (Roth 2010, p 42). Camille hit the coastline as a powerful Category Five hurricane on the Saffir-Simpson Scale (Roth 2010). Also, four Category Four hurricanes have struck the Louisiana coast from 1850 to 2004 (Moreau 2006). Two out of these four hurricanes to affect Louisiana occurred within the decade prior to the USACE’s LPHPP proposals. Although they made landfall in southwestern Louisiana and eastern Texas, Hurricane Audrey of 1957 and Hurricane Carla of 1961 were both stronger hurricanes than the SPH, and both created storm surges in the Mississippi River Delta that led to flooding in the New Orleans area (Roth 2010). The same year that the LPHPP was produced Hurricane Betsy, a strong Category Three storm, struck just east of New Orleans (Roth, 2010). Betsy created a storm surge of over ten feet along the Mississippi River that sent nine feet of water into New Orleans East and Chalmette, inundating these regions for days (Roth 2010).

It is important to note the underrated SPH, because it justified the piecemeal levee system. If the SPH had been made equivalent to a Category Five hurricane, thus necessitating a superior hurricane protection plan, the fragmented construction and restoration produced by the LPHPP would not have been acceptable. However, the SPH was used as the framework for the New Orleans hurricane protection system for the next fifty years, and the lower sense of risk may have thus contributed to the catastrophe produced by Hurricane Katrina (Moreau 2006).

The Construction of the Pre-Katrina Landscape – Reassessment and Repeated Mistakes: 1965 to 2005

The LPHPP construction, based upon the Barrier-Low-Level Protection Plan, did not commence until the late 1970s (Rogers 2008). When construction finally did start, it was carried out in a piecemeal fashion (Rogers 2008; ASCE 2007). Concrete was added to the French Quarter levee, levees at the east end of Plaquemines Parish were raised and fortified, and steel-sheet pilings were used to strengthen the IHNC (Van Heerden and Bryan 2006). These improvements benefitted specific areas of New Orleans, but the USACE neglected smaller communal levees in order to revamp the larger ones first (Rogers 2008). Thus, the smaller, local levees were reinforced to the USACE's height standards by local levee boards, not the Army Corps of Engineers (Rogers 2008; ASCE 2007). While built up to USACE height standards, the local levee boards neglected to enlarge the levees' bases, adding weight to a weakening base (Rogers 2008; ASCE 2007). Notably, the local levee boards made reinforcements along the 17th St. Canal levee and the London Avenue Canal levee, two levees that were breached by storm surges from Lake Pontchartrain during Hurricane Katrina (ASCE 2007).

By 1982, about 50% of the hurricane protection system was completed (Van Heerden and Bryan 2006). The slow rate of construction was largely due to federal and state funding constraints and new legislation passed by Congress, such as the Environmental Policy Act and the Clean Water Act, that required Environmental Impact Statements (EIS) (Moreau 2006). The EIS that the USACE drafted resulted in a forced shut down of barrier enhancement projects, because much of the B-LLP called for dredging and wetland removal in order to maintain levees and support canals, measures that did not meet the terms of environmental legislation (Moreau 2006). Furthermore, while complying with federal requirements, the USACE also had to work with local levee boards within the Mississippi River Commission (Rogers 2008). Most local levee bureaus supported less costly improvement plans in order to save taxpayer dollars (Rogers 2008). Alternative plans, such as the grandious HLP, would have added an unsightly 300 meter-wide embankment on the shores of Lake Pontchartrain, along with the massive floodgates displacing some homes along the coast (Rogers 2008); local officials and communities would not agree to such disruptions (Rogers 2008).

In response to the slow onset of construction, the U.S. government instructed the USACE to reassess the 1965 LPHPP (Moreau 2006). The reevaluation began in 1984, upon which the USACE noted that the protection in place at the time was incomplete and not adequate enough to protect against the SPH (Richardson et al 2008). In addition, levees and floodwalls in certain areas were found to be lower than their specified height and lacking uniform construction materials (Richardson et al 2008). This evaluation prompted two new plans for hurricane protection in the region: the Parallel Protection Plan and the Frontal Protection Plan (Moreau 2006). The USACE endorsed the Frontal Protection Plan which would build floodgates and high-functioning pumps at all major canal entrances and create a massive floodgate at the entrance to Lake Pontchartrain (Van Heerden and Bryan 2006); this plan would prevent storm surges from being able to enter the city through the canals and Lake Pontchartrain, effectively eliminating a significant portion of flooding in New Orleans (Moreau 2006). The local levee boards, however, supported the Parallel Protection Plan, which yet again called only for elevating the floodwalls and levee systems around the canals and included some barrier enhancement along the Pontchartrain lakefront (Moreau 2006); this further exacerbated the fragmented network of levees, because reinforcements were not uniform across the levee system (ASCE 2007).

Federal and state funding was allocated for the Parallel Protection Plan (Moreau 2006). Piecemeal construction ensued in which different materials were used to attach sections of one type of levee system to another (ASCE 2007). Figure 9 depicts levees at the 17th St. Canal and the London Avenue Canals in which the USACE connected concrete reinforcements with steel-sheet piling reinforcements (ASCE 2007, p. 64). Nearly all areas where this sort of bridging between two different levee styles occurred failed during Hurricane Katrina (ASCE 2007). Of the 350 miles of levees and floodwalls, 169 miles were damaged during the storm, and roughly 50 locations were either breached or overtopped by the storm surge (ASCE 2007).

Figure 9: Levees demonstrating use of different building materials; these levees failed during Katrina. Source: ASCE. 2007.

Additionally, levee and floodwall elevations varied throughout the network (ASCE 2007). While the Army Corps of Engineers mandated specific height requirements, these requirements differed depending on the materials used in levee section (ASCE 2007). For example, the type of floodwall known as the “I-Wall” called for an earthen levee to support its frame higher than a regular earthen barrier (ASCE 2007). When these two sections were connected, the I-Wall levees stood significantly higher than the earthen levees. Figure 10 reveals a portion of the 17th St. Canal levee in which this scenario occurred. The I-Wall levee was connected to an earthen barrier, the barrier was lower in elevation, and the lower barrier was overtopped by the powerful storm surge (ASCE 2007).

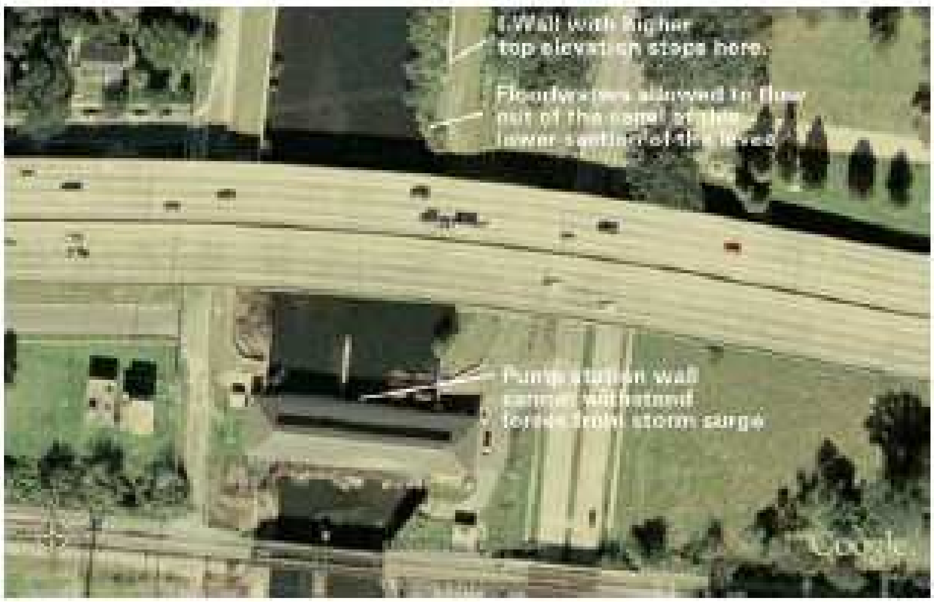

Figure 10: 17th St. Canal – Different elevations of levees along the same canal resulted in overtopping of the lower sections during Hurricane Katrina.. Source: ASCE. 2007.

The Army Corps of Engineers estimated finishing the Parallel Protection Plan by 2008; later adjustments pushed that date back to 2015 (Moreau 2006). Hurricane Katrina made landfall in Louisiana on August 29, 2005, ten years before levee refurbishment was set to be complete. Even if the levee construction had been completed before Katrina struck, the Parallel Protection Plan was still modeled after the Standard Project Hurricane, leaving the city of New Orleans at the mercy of a powerful Category Three hurricane (ASCE 2007). David H. Moreau, a researcher at the University of North Carolina at Chapel Hill, considers the history of the New Orleans levee system a “repititious cycle” of expansion and development, construction and protection, landscape manipulation and degradation, and failure followed by new development (2006, p. 11). Moreau criticizes the U.S. Army Corps of Engineers stating that they had an “overreliance on 50-year-old forecasts” that they used to “justify their projects” (2006, p. 11).

The levee system in New Orleans that faced Katrina in 2005 was what the American Civil Society of Engineers called “a system in name only – in reality it is a disjointed agglomeration of individual projects that were conceived and constructed in a piecemeal fashion” (ASCE 2007, p 63). Had the system been built with congruencies throughout and based upon the maximum possible hurricane, catastrophe might have been averted.

Wetland Decline

Wetland decline has become a serious and complex issue for southeastern Louisiana. The wetlands provide ecosystem services by protecting inland regions from storm surges, functioning as sponges during heavy flooding events, and filtering out pollutants in the water (USGS Coastal and Marine Geology Program 2010). Over the past 150 years the Lake Pontchartrain watershed has been transformed by massive drainage of low-lying basins, cypress swamps, and marshes (Kindinger 2001). Estimates from the NASA Earth Observatory indicate that from 1937 to 2000 up to 35 square miles of coastal wetlands were lost per year, or approximately 1,900 square miles of wetlands disappearing in 63 years (NASA 2005). The three main causes of this swift wetland decline are natural land subsidence processes, rapid growth and urban expansion, and canal dredging (USGS Coastal and Marine Geology Program 2010; CWPPRA 2011; Van Heerden and Bryan 2006; Moreau 2006).

The wetlands of southeastern Louisiana are part of the Pontchartrain Basin watershed making up one of the largest estuaries in the United States (Kindinger 2001). The basin is situated to the east of the Mississippi River and extends northward through Jackson, MS (USGS Coastal and Marine Geology Program 2010). The southern extent of the Pontchartrain Basin joins with the Mississippi River Delta creating a landscape of fresh water swamps, brackish water estuaries, and salt water marshes (USGS Coastal Marine Geology Program 2010). The soils in and around Lake Pontchartrain are mostly comprised of silts, clays, and sands along with organic material such as leaf litter, shells, and rootlets (Kindinger 2001). These marshy soils are often saturated with water creating a highly compressible, unstable land surface (Van Heerden and Bryan 2006).

The American Civil Society of Engineers noted that, “New Orleans is sinking” (ASCE 2007, p 8); the land undergoes a process known as subsidence, a natural process of soil compression due to the decay of the organic materials present in the soils (ASCE 2007). Before human intervention in the natural hydrology of New Orleans, land subsidence was counterbalanced by sediment deposition from the Mississippi River, maintaining an at-sea-level landscape; however, fresh sediment layers are now prevented from deposition over old layers due to the massive flood control systems established along the entirety of the Mississippi River (ASCE 2007). This has resulted in the below-sea-level surfaces present today. Hence, the flood control measures taken in the last two centuries, such as the construction of the Bonnet Carre Spillway, have actually sped up natural land subsidence processes creating a sinking city (NASA 2006).

It is important to note that the land is sinking when discussing wetland decline in southeastern Louisiana, because land subsidence has been attributed as one of the leading factors in wetland decline in the New Orleans region; land subsidence allows increased levels of salt water to infiltrate sensitive brackish water wetlands (CWPPRA 2011). Brackish water estuaries comprise 24% of the total wetlands in the Pontchartrain Basin, functioning as protective, salt water barriers for inland fresh water marshes and cypress swamps (CWPPRA 2011). Due to land subsidence, the brackish water marshes have been more suseptable to encroaching salt water from the Gulf of Mexico (CWPPRA 2011). Even subtle changes to the amount of salt water in a brackish water ecosystem can have severe consequences, such as the inability of wetland vegetation to adapt to the rapid changes in saline content resulting in high levels of plant die-off and wetland loss (CWPPRA 2011).

Increased saline levels in brackish water ecosystems is crucial for the Crescent City, New Orleans East, and the eastern bordering wetlands. New Orleans East historically has had the greatest land subsidence throughout the delta plain, and the region is already five to eight feet below sea level (NASA 2006). New Orleans East also has a large land area covered by wetlands and is bordered by the Borgne Land Bridge, the largest brackish water marsh in the region (CWPPRA 2011). The Borgne Land Bridge separates Lake Borgne and the Gulf of Mexico from Lake Pontchartrain, functioning as a line of defense from damaging storm surges (CWPPRA 2011). Research conducted by the Coastal Wetlands Planning, Protection, and Restoration Act Managing Agencies (CWPPRA), a conglomeration of NOAA, USACE, the National Resources Conservation Service, and more, has shown that since 1932 approximately 24% of the Borgne Land Bridge has been lost, largely due to land subsidence and the resulting spike in saline content (2011). Consequences from such a high rate of wetland decline include increased erosion along the shorelines of Lake Pontchartrain and Lake Borgne, which further exacerbates the issue of wetland loss, and increased storm surges passing from the Gulf of Mexico through Lake Borgne to Lake Pontchartrain, putting more people and property at risk to flooding (CWPPRA 2011).

In addition to land subsidence, increased development of wetland regions has led to substantial wetland decline. When the population of New Orleans was booming in the late 1800s and early 1900s, areas outside of New Orleans Proper were sought for development (Moreau 2006). Figure 11 depicts the city of New Orleans before the districts of Lakeview and Gentilly were built in 1849 (ASCE 2007). The land cover feature that separated central New Orleans from Lake Pontchartrain was fresh water marshes and cypress swamps (Moreau 2006). The swamps acted as a buffer from lake-side flooding or flooding from storm surges that could assault New Orleans from the north, the same direction as one of the two main storm surges that Hurricane Katrina produced (ASCE 2007). When lakefront development was seen as the next best steps for the city, the swamps were drained resulting in significant wetland die-off (Moreau 2006). Furthermore, soils from other wetlands were collected and redistributed in the form of floodwalls along the shores of Lake Pontchartrain to protect the new developments (Moreau 2006; USGS Coastal and Marine Geology Program 2010). This was known as the Lakefront Development Project of 1926 that resulted in significant wetland drainage and loss (Moreau 2006).

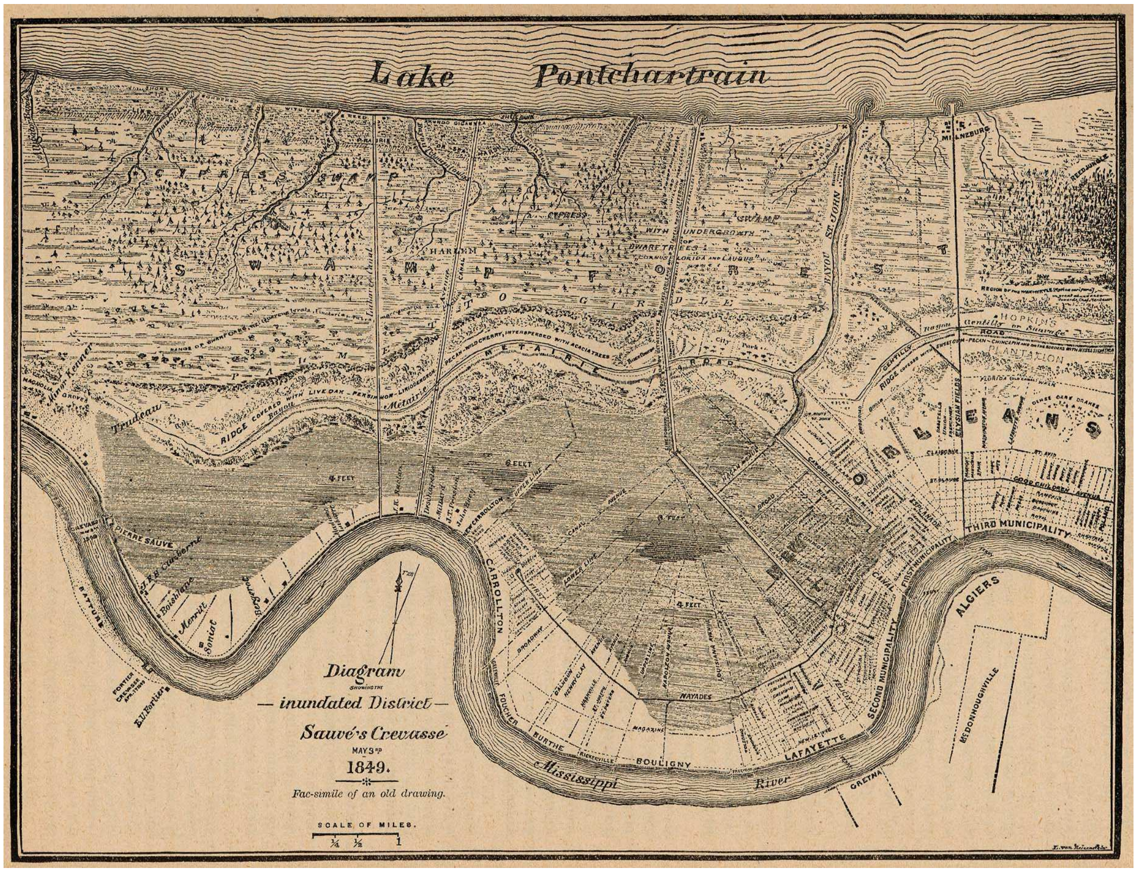

Figure 11: Historical Map of New Orleans displaying former swamp lands to the north of the city. Source: ASCE. 2007.

In terms of development, the greatest devastation to local wetlands occurred between 1950 and 2000 when the brackish water, marsh land barrier east of the IHNC was urbanized. Deemed a "high-risk venture" by the USACE because of its exceedingly low elevation, the federal government supported levee construction east of the IHNC so that new residential areas could be built, called New Orleans East (Moreau 2006, p 24). The notion that the New Orleans region would need additional residential land cover came from population projections modeled after the rate of growth from 1900 to 1950, in which the population of New Orleans doubled (USGS Coastal and Marine Geology Program 2010). However, the rate of population growth leveled out in the New Orleans area soon after the population boom, negating the full need of the New Orleans East developments (USGS Coastal and Marine Geology Program 2010). As a result, the wetlands were replaced by non-porous infrastructures that were not necessary to the city's overall expansion, and the natural wetland barrier was destroyed.

In conjunction with the promoted development of New Orleans East in the 1950s, federal and state government also sought to build a shorter navigation route from the Gulf of Mexico to the Port of New Orleans (USACE 2012). The proposed canal would have a duel function as a safer shipping route while encouraging residential settlement in New Orleans East (USACE 2012). The canal was named the Mississippi River Gulf Outlet (MRGO, pronounced “Mister Go”) and was completed in 1968 (USACE 2012). MRGO allowed ships to avoid the unpredictable mouth of the Mississippi River and saved shippers time by cutting off the remaining 120 miles of the winding lower Mississippi River (USACE 2012). Figure 12 displays MRGO beginning in the Gulf of Mexico and joining up with the IHNC.

Throughout its construction and usage, MRGO has had profound effects upon the surrounding ecosystems. The 38-foot deep and 500-foot wide canal was dredged through brackish water marshes, cypress swamps, and smaller bays (USACE 2012). In fact, the construction of the 75 mile long MRGO directly removed 27,600 acres of wetlands and salinized tens of thousands of additional acres of sensitive wetland habitats (Freudenburg et al 2008). Rather than an “outlet,” MRGO functioned as an “inlet” for salt water to bombard sensitive fresh and brackish water vegetation (Freudenburg et al 2008). In addition, MRGO served as a funnel for the storm surge during Hurricane Katrina, which resulted in multiple levee breaches along the IHNC, the major cause of flooding in St. Bernard’s Parish, the Lower-Ninth Ward, and New Orleans East (ASCE 2007; Freudenburg et al 2008). This flooding was not only

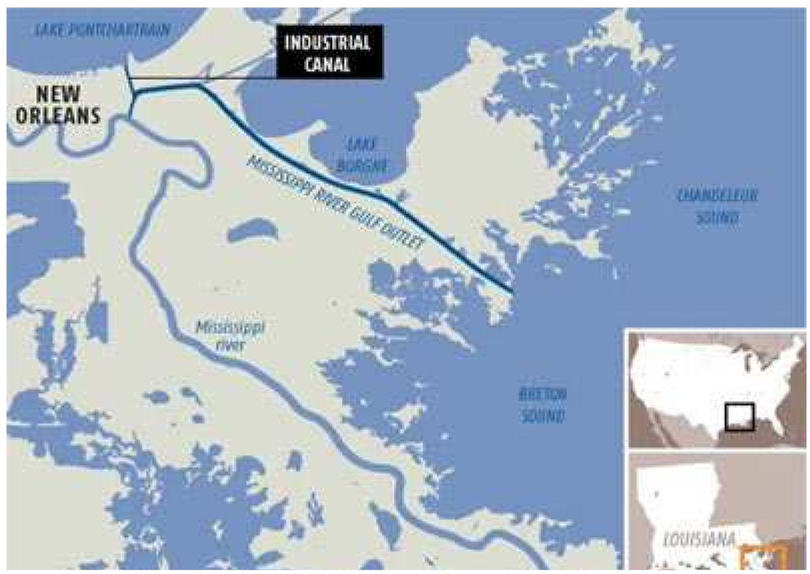

Figure 12: Map of MRGO – demonstrates quicker, more direct route to Port of New Orleans. Source: USACE. 2012.

problematic for people and property, but also devastated the surrounding wetland ecosystems (Freudenburg et al 2008).

MRGO is just one of multiple canals that characterize the lower-river delta. Other canals have been constructed by oil and gas companies in order to better navigate the oil and gas-rich marsh lands (Van Heerden and Bryan 2006). While MRGO and the canals constructed by the oil companies served to improve the navigation of the Mississippi River Delta, they did so at the expense of the region's natural hurricane defense system (Freudenburg et al 2008).

When Hurricane Katrina collided with southeastern Louisiana, the network of wetlands that protected the coastline had been hindered by an amalgamation of human influence and natural processes. Because of land subsidence and saline encroachment, development, and canal dredging, Katrina struck a deteriorating, sensitive landscape that was unable to function as an absorbent barrier. These factors have crippled the wetlands of southeastern Louisiana and may have exacerbated the damages produced by Hurricane Katrina.

Social Vulnerabilities

The reasons for Hurricane Katrina's destruction were not limited to preexisting features of landscape and piecemeal engineering. The citizens of the Mississippi River Delta were also struck by a storm that altered their lives forever. Estimates of lives lost during Hurricane Katrina range from 1300 to as high as 1800 (Richardson et al 2008); yet, studies performed by NOAA and the NWS suggest accurate disseminations of warnings with sufficient time to evacuate the New Orleans region (Johnson 2006). Research by Joseph E. Trainor et al suggests that non-evacuees were in fact aware that a powerful storm was headed their way (2006). With a functioning warning system in place, many were left questioning why there were such devastating consequences. Susan L. Cutter, Christopher T. Emrich, and fellow social scientists argue that "social vulnerabilities" of the non-evacuees, resulted in a very high number of “excess mortalities” or untimely deaths (Cutter and Emrich 2006; Trainor et al 2006; Gall 2011, p. 159).

Social vulnerabilities are defined as “the susceptibility of social groups to the impacts of hazards, as well as their resiliency, or ability to adequately recover from them” (Cutter and Emrich 2006, p. 103). Social vulnerabilities are byproducts of preexisting social inequalities; they embody population characteristics such as age, gender, and class as well as personal factors such as physical mobility, knowledge and awareness of evacuation routes and emergency services, social networks, fears of looting or physical harm, and more (Cutter and Emrich 2006; Trainor et al 2006). Trainor et al describes people with social vulnerabilities as not having “the means” to evacuate or execute other self-protective measures (2006, p. 314). Many citizens of New Orleans were without the means, forcing them to weather the storm with limited resources and aid (Trainor et al 2006).

Different social vulnerabilities have been identified as the primary cause of such high death tolls and such high rates of non-evacuation. Cutter and Emrich note that two of the greatest determinants of social vulnerability in Orleans Parish were race and class (2006). Most of the non-evacuees during Hurricane Katrina were lower-class, African-American citizens (Cutter and Emrich 2006). Cutter and Emrich note that 27% of this particular demographic did not own an automobile, encumbering their ability to evacuate. Additional research by Melanie Gall indicates that age may have been the most influential social vulnerability during Hurricane Katrina (2011). An analysis of the victims of Hurricane Katrina indicated that 50% of the victims were older than 75 years old, and 85% of the victims were 51 years or older (Gall 2011). Although age itself does not necessarily make an individual more vulnerable, it’s correlated with reduced physical and mental abilities and chronic diseases (Gall 2011). This implies that many Katrina victims may not have been able to mobilize quickly, if at all, or comprehend the impending dangers.

Trainor et al sights a different social vulnerability as playing a highly significant roll in the Katrina disaster. Trainor et al interviewed non-evacuees asking why they did not or could not evacuate.

Non-evacuees suggested the following reasons for remaining at home during the storm: physical immobility, financial limits/costs, lack of personal transportation, government failure to provide transportation, lack of knowledge of evacuation routes, lack of knowledge of public emergency protocol, cultural ties to neighborhood, weak personal and social networks, “wishful thinking,” past experiences, fears of robbery or looting, and the “normalcy bias” (Trainor et al 2006). Trainor et al noted that “wishful thinking,” past experiences, and the “normalcy bias” were the top three reasons among his interviewees for choosing to stay in New Orleans (2006). “Wishful thinking” is what Trainor et al defines as a psychological phenomenon that people undergo during times of imminent threat in which they hope or pray that a natural hazard will redirect its course and not cause harm to themselves or personal property (2006). This mindset was a common problem among non-evacuees during Hurricane Katrina, placing them at greater risk than those who chose to heed the public warnings (Trainor et al 2006). Similarly, the “normalcy bias” kept people from leaving; this occurs when people feel as though emergencies are a routine, everyday occurrence and they should simply go on with their normal activities (Trainor et al 2006). The “normalcy bias” occurs in many emergency situations as a coping mechanism for those who do not trust in warning systems or the organization managing warnings (Trainor et al 2006).

Trainor and his fellow researchers also discovered that past experiences with disasters impacted people’s decisions to stay (2006). Many of the non-evacuees had lived through Hurricane Camille in 1969; with Katrina being downgraded from a Category Five to a Category Three, they felt as though they could handle a weaker storm (Trainor et al 2006). Past experiences often affect people’s behavior before, during, and after a disaster (Cutter and Emrich 2006); decisions that place them in greater danger are justified through the rationale that they have lived through a disaster before, so they can survive the next one (Trainor et al 2006).

Lastly, Freudenburg et al poses that the overall concentration of populations should be considered when assessing the social vulnerabilities of the New Orleans populous (2008). In New

Orleans, there was a large clustering of people in a high hazard region. This clustered effect is what Freudenburg et al notes as setting the stage for the catastrophe in the first place (2008). If the population had not been so concentrated in a region renowned for its hurricane activity, Katrina would not have impacted so many lives (Freudenburg et al 2008).

While different studies may suggest that certain characteristics outweighed others in terms of the capability of the New Orleans populous to plan, respond, and recover from Hurricane Katrina, the researchers all suggest that in most circumstances there was a multiplicity of social vulnerabilities that inhibited survival techniques. Rather than there being one, dominating social vulnerability that dictated the nature of victimization, all factors interplay with one another creating an extremely vulnerable population in New Orleans. The academics mentioned above also suggest that not enough research has been done on social vulnerabilities and cite a need to prevent “tragedies” like Katrina from repeating (Freudenburg et al 2008, p. 1029). Cutter and Emrich disapprove of “broad-brush approaches” that create overarching formulas for addressing the social vulnerability issue. Instead they suggest individual and community level based planning that assesses who has the greatest need (2006, p. 112).

In sum, it is important to show that the citizens of New Orleans exhibited social vulnerabilities before Katrina struck, because these vulnerabilities were amplified during and after the storm. New Orleanians were unable to prepare for the storm due to these social vulnerabilities, and therefore they were unable to defend themselves against the rising waters resulting in a shocking death toll (Gall 2011). Furthermore, the social vulnerabilities exhibited by the citizens of southeastern Louisiana were heightened by the piecemeal hurricane protection system and the hindered natural protective environment, because these features were unable to protect a defenseless population.

Future Mitigation and Conclusions

Three major reasons for the extent of destruction caused by Hurricane Katrina have been identified: piecemeal construction of the hurricane protection network, wetland loss, and elevated levels of social inequalities. These three factors contributed to the loss of over 1,500 lives, widespread damage, and the extreme financial burdens of recovery. There are many arguments eager to explain the devastation of Hurricane Katrina: government initiatives failed at nearly all levels (local, state, federal), FEMA lacked proper decision-making skills and capable upper-management personnel, or that too much emphasis within emergency management had been redirected to terrorism since the terrorist attacks on September 11 creating confusion in terms of protocol and policies. However, these critiques blame the storm's devastation on short-term factors that emerged as a result of the storm. The reasons for disaster presented in this paper are long-term, preexisting conditions that created an environment vulnerable to Katrina's power. Therefore, these preexisting conditions require mitigation efforts to lower the probability of another Katrina-like event.

By utilizing a tool developed by FEMA known as "STAPLEE" I have analyzed several potential ways in which we might lower the probability of another Hurricane Katrina catastrophe from occurring. STAPLEE allows emergency managers to assess the ways in which a proposed hazard mitigation plan is effective or ineffective. STAPLEE stands for social, technical, administrative, political, legal, economic, and environmental – the areas of society that would be affected by the mitigation plan. Social refers to community acceptance; technical refers to feasibility of a mitigation goal; administrative refers to capable staffing and allocation of funding; political addresses political support; legal looks at legal limitations and potential challenges to authorities; economic infers costs and benefits of a mitigation plan; and environmental addresses the impacts on surrounding habitats and effects on global environmental goals.

Based upon the three dimensions of disaster, Table 4 analyzes possible mitigation actions that have been proposed in the wake of Katrina to decrease the loss of life and property in the future.

Each action is rated on each of the STAPLEE dimensions based on the history and assessment of the main causes of the Katrina disaster described earlier; negative (-) symbols indicate an undesirable or impractical condition or outcome; positive (+) symbols indicate a positive condition or outcome; the zero (0) indicates a neutral or indeterminate condition or outcome.

STAPLEE Mitigation Plans	Social	Technical	Administrative	Political	Legal	Economic	Environmental
Levees: Do Nothing/ Abandon City	**(-)** Historical significance of city is strong; public outrage would ensue	**(-)** Getting people out of the city will be a problem; unknown how to decommission a city	**(-)** Unclear how local government dissolves itself	**(-)** Heavy political opposition; some support as witnessed after Katrina	**(-)** Land ownership and compensation will likely cause multiple legal issues	**(-)** Large economic losses due to loss of major port/ tourist destination	**(-)** Pollution due to abandoned city not properly managed/ deactivated
Levees: Rebuild to Status Quo	**(-)** Public will be upset that standards did not improve	**(0)** Requires same technical operations as the past 40 years	**(0)** USACE would continue to be in charge of levee construction	**(-)** Political outcry due to lack of government initiative	**(-)** Lawsuits likely due to repetition of failed system	**(-)** High costs for levee system repairs	**(-)** Continued environmental degradation/ negative ecosystem effects
Levees: Address Engineering Problems/ Fix Height Problems and Different Materials Issues	**(+)** Public will support improving the levees to benefit their properties and safety	**(-)** May require removing some levees entirely; could be difficult	**(0)** USACE would continue to be in charge of levee construction	**(+)** May create political support for levee revamping	**(+)** May increase property values with revamped levees	**(-)** Higher costs due to improved levee building	**(-)** Continued environmental degradation/ negative ecosystem effects
Levees: Mitigate to Category Five Storm	**(+)** Public will support improving the levees to benefit their properties and safety	**(-)** May require removing all levees entirely; could be difficult	**(-)** Outside staffing needed to assess USACE's Cat-5 storm protection	**(-)** May create political opposition due to tax increases	**(-)** Will likely cause home displacement and lawsuits over reclaimed land compensation	**(-)** Extremely high costs due to improved levees; may bankrupt city/ state	**(-)** Continued environmental degradation/ negative ecosystem effects

STAPLEE							
Mitigation Plans	Social	Technical	Administrative	Political	Legal	Economic	Environmental
Wetlands: Protect Wetlands/ Limit Public Use	**(0)** Public may support wetland protection; may be discouraged by land use restrictions	**(0)** Overall limited technical challenges	**(-)** May need more staff in U.S. Dept. of Fish and Wildlife or local wetland protection offices	**(+)** Public support for “green” actions taken by government	**(-)** Land restrictions may cause legal battles; issues with former land use capabilities	**(-)** Substantial costs due to erecting of barriers/ signs	**(+)** Environmental benefits due to decreased land disturbance/ possible wetland re-growth
Wetlands: Aggressive Reversal of Wetland Decline	**(-)** Banned use of public lands will create public outcry	**(-)** May be difficult to replant wetlands/ facilitate re-growth	**(-)** May need additional staffing to replant/ monitor wetlands	**(-)** May be seen as an overly aggressive political move	**(-)** Restricting land use may cause legal action from oil and gas companies	**(-)** High costs due to improving wetland regions	**(+)** Wetland re-growth possible; habitats restored
Vulnerabilities: Increase Community Planning/ Improve Evacuation Plans/Routes	**(+)** Public will support better evacuation plans and increased focus on poor areas	**(0)** Not a complex technical task	**(-)** Need to hire city planners to reassess evacuation routes and community education leaders	**(+)** Political support for helping the vulnerable	**(+)** Relatively minimal legal problems	**(-)** Some cost increases for paying staff members and city planners	**(0)** Not directly related to environment; may increase pollution from increased use of transportation
Vulnerabilities: Make Vulnerable Populations Only Focus of Hazard Planning	**(-)** Narrow focus of mitigation likely to upset other members of public	**(0)** Not a complex technical task	**(-)** Need to reassign staff; hire experts in social vulnerabilities and emergency management	**(-)** Political outrage over narrow focus of hazard planning	**(-)** Law suits over negligent government	**(0)** Narrow scope of emergency planning may free up money	**(-)** Environmental issues may be neglected altogether

Table 4: STAPLEE tool assessing potential mitigation plans for the three major dimensions of disaster during Hurricane Katrina. Source: Created by Sarah McKinnell for “Dimensions of Disaster: Landscape, Levees, and the Least Fortunate.” 2012.

Based upon Table 4, it is evident that the remedies to the piecemeal levee construction, wetland decline, and social vulnerabilities are complex. Utilizing STAPLEE as an assessment tool, however, can aid in deciding the next best steps for mitigation in New Orleans and in other coastal regions. Choosing to abandon the city and do nothing in response to the levee failure had negative results in every category of STAPLEE, indicating that this solution should not be implemented. Rebuilding the levee systems to the pre-Katrina standards had similar results, suggesting that this mitigation plan would be ultimately ineffective. Rebuilding the hurricane protection system to withstand a Category Five storm also produced negative effects. Although it would more than likely receive public approval so that there is not a Katrina-repeat, the feasibility of this endeavor could potentially bankrupt New Orleans, the state of Louisiana, and the USACE.

Addressing the previous engineering faults, however, may yield constructive results. Creating a unified, reliable hurricane protection system with conformity in construction materials, equivalent heights throughout, and constructed by a singular organization may provide viable hurricane protection throughout the New Orleans region. Cost increases can be expected, along with an increased difficulty in the technical engineering of the levees, but overall the public would support levee improvements that do not result in significant tax increases, as would be expected with redoing the levee system to withstand Category Five hurricanes. In addition, legal complications would be minimal and property values may even increase in New Orleans due to enhanced storm protection.

Wetland decline would best be mitigated over a long-term time scale. By limiting public use of highly vulnerable wetlands and attempting to reconstruct wetland habitats, improvements may be seen over time; however, other factors play a role in wetland decline, such as land subsidence, which could hinder the wetland reclamation process altogether. Overly-aggressive actions that bar people access to job sites and recreational activities would more than likely damage the economy, lack in political support, and bring about technical implication issues. Similarly, too much emphasis on populations with high social vulnerabilities may hinder New Orleans' overall ability to react to disaster, because it neglects other populations that are at risk as well. Increased community planning may help the most vulnerable populations in New Orleans by preparing them with the knowledge and tools to evacuate the next time a storm comes.

In conclusion, the mitigation efforts proposed and analyzed with the STAPLEE tool might improve the three preexisting conditions that exacerbated the disaster in 2005. With better community planning and emergency response tools, the people of New Orleans might reduce their social vulnerabilities and be better prepared for the next disaster. Further wetland decline might be prevented and re-growth could result in a more stable landscape. Future damages to infrastructure, property, and people might be prevented with adjustments and improvements made to the previous, piecemeal hurricane protection system. Learning from catastrophes and analyzing the conditions that generated widespread destruction allows mitigation planners, governments, emergency response organizations, engineers, and citizens to improve mitigation strategies and decrease the vulnerabilities of property and people.

Afterword

In addition to increased community planning, wetland reclamation efforts, and addressing and improving upon the missteps of previous engineering, I think that mapping can be used as a tool to improve upon these three dimensions of disaster. Through the use of modern mapping, including Geographic Information Systems (GIS), remote sensing, LANDSAT imaging, and more, vulnerable landscapes, levee systems, and populations can be identified and analyzed for future mitigation planning. For example, by combining U.S. Census data with terrain elevation data in a GIS, we can create maps that identify where high-risk populations reside, as well as which groups are more likely to experience flooding because they live in a below or at-sea-level area. With these maps, emergency managers can focus evacuation planning and public awareness outreach on the identified vulnerable communities. This will ensure that when another disaster occurs, these communities may be more capable of defending themselves or be given priority in terms of where resources are allocated.

Mapping can also be used to show spatial – temporal relationships of the regions natural habitats. By using LANDSAT imaging and other satellite imagery, we can map wetland decline or growth over time. This will allow emergency planners to identify areas with limited natural storm surge barriers. The USACE can run detailed analyses on storm surge patterns and wetland availability to assess where levees may need to be higher than expected due to a lack of a wetland barrier. Mapping can also be used to monitor levee construction progress. Richardson et al noted that the USACE used maps that were "more than a decade old" when constructing levees and floodwalls in New Orleans (2008, p 36). This is problematic especially when building a hurricane protection system on a landscape with significant land subsidence. The land surface data may have changed within that decade creating substandard levees that do not meet height requirements. Similarly, events such as Hurricane Katrina can alter the landscape entirely removing portions of land and changing local hydrologic systems (NASA 2005). Lastly, mapping can ensure better quality construction if conducted on a routine basis, which would improve the overall hurricane protection system.

Spatial analysis tools are fundamental to mitigation efforts, and mitigation efforts are essential for disaster resilient societies. With greater and more reliable use of mapping, emergency organizations such as FEMA can have eyes on a hazard zone before disaster strikes. Relationships can be predicted in advance based upon location, specific demographic characteristics, and established defense mechanisms in which people may be more susceptible to loss of life and property. By analyzing previous disasters, like Hurricane Katrina, we become aware of the shortcomings of human and environmental interactions. Wetland decline, piecemeal levee construction, and social vulnerabilities worked together to generate serious shortcomings for the entire New Orleans region. Mapping as a foundational tool for mitigation preparations can decrease these shortcomings and establish a greater understanding of the vulnerabilities all people exhibit in the face of disasters.

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